COMPARISON OF PARTIALLY MISCIBLE WORKING MIXTURE OF ABSORPTION HEAT TRANSFORMER

By

Amirul Bin Abdul Salam
11887

A project dissertation submitted in partial fulfillment
of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CHEMICAL ENGINEERING)

SEPTEMBER 2012

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CERTIFICATION OF APPROVAL

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Approve by,

…………………………….

(Dr Rajashekhar Pendyala)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work obtained herein have not been undertaken or done by unspecified sources or persons.

……………………………….
AMIRUL BIN ABDUL SALAM

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ABSTRACT

This project is intended to evaluate the potential of partially miscible working mixture where the separation of working mixture is achieved by the cooling of working mixture at low temperature. This working mixture is operated by absorption heat transformer (ADHT) the simulation model has allowed the evaluation of temperature lift and Coefficient of Performance (COP) by the system. Absorption heat transformer (AHT) operated by lithium bromide-water (LiBr-H_2O) solution is used as comparison for the COP. The evaluation of ADHT has been done successfully and compared with experimental data and simulation data of AHT operated by LiBr-H_2O .

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CHAPTER 1: INTRODUCTION

1.1 Background of Study

Absorption heat transformer is a cycle where the temperature of waste heat is elevated to the higher value than any of the input heat supplied to the system. This system is using a medium or working mixture to absorb the energy from waste heat then released the heat on a higher temperature after undergoes physical and/or chemical transformation. The waste heat can be from industries process such as cooling water, effluent, condensate, moisture, and condenser heat from refrigeration plants. The absorption cycle is a closed system requiring two working fluids, a refrigerant and an absorbent. These working mixture are usually combination of ammonia/water, or water/lithium bromide (LiBr). The mechanical compressor used in the vapor compression heat pump is replaced by two heat exchangers; the absorber and the desorber and a liquid pump. These heat transformers can achieve delivery temperatures up to 150ºC from the waste heat of 80ºC -100ºC, typically with a lift of 50ºC-70ºC. The range of Coefficient of Performance (COP) under these conditions is 0.42 to 0.48.

During the last decade heat transformer technology has attracted many attentions as one of the promising energy saving technologies. There are several types of heat transformer such as Absorption Heat Transformer (AHT), Absorption Demixing Heat Transformer (ADHT) and Multi Stage/ Layer Heat Transformer (MSHT). This technology is used in heating and cooling of process streams, water heating for washing, sanitation and cleaning, drying/dehumidification and evaporation distillation concentration. The advantage of a heat transformer is that it works with a driving heat force at a medium temperature level (60ºC-100ºC), which is partly transformed to a higher temperature level, with the remainder part being released to the surroundings. The heat transformer needs only a small input of mechanical energy. The limiting temperature in the absorber is about 150^{o}C. The technical barrier is the restriction in temperature lift.

1.2 Problem Statement

After the energy crisis in 1970, the price of natural gas and oil used to fuel steam boilers drastically increased. Thus, people are trying to optimize the energy production and consumption within the plant. The technology comes up with the idea to use waste heat as the source of recycle energy and absorption heat transformer is one of them. Generally, industrial waste heat is produced around 50-100^{o}C and released to the environemt because it is useless to the industrial process. The absorption heat transformer (AHT) is a technology for recovering industrial waste heat and convert it to the high quality heat for industrial uses.

Commonly, the absorption heat transformer is operated by Water-Lithium Bromide as working mixture. However, this system is facing a limitation in producing high output energy. Because of Lithium Bromide is a salt, at certain temperature and pessure crystalizaton will occur thus leads to the corrosion in pipeline. In addition, this system also need high energy input in order to separate the working mixture. Thus, the cost for energy comsumption also will be higher.

In order to overcome this problem, absorption heat transformer with different working principle is introduced . This system operated by the partial miscible binary working mixture where there is no costly energy needed. This project will focus on the performance of this system and the potential of working mixture.

1.3 Objective

There is several main purpose of this project:-

- To develop the model of absorption heat transformer.
- To run a simulation based on the developed model.
- Evaluate the performance and potential of new working mixture.
- To investigate the temperature lift and thermal yield of heat transformer by partial miscible binary working mixture.

1.4 Scope of Study

This project will be focusing on the simulation of the AHT by HYSYS as simulation software. The data will be collected and analyzed in order:-

1. To evaluate the AHT performance.
2. To study the influence of the operating parameter.
3. To study the chemical/ physical properties and also the behavior of the working mixture.
4. To assess the performance of working fluid.

1.5 Relevancy of The Project

The increasing of the price oil and gas for generating steam leads to the finding of new alternative. This project has potential:-

1. Lower cost of energy regeneration from waste heat.
2. Lower operating cost.
3. Overcome the crystallization problem in current technology.
4. Reducing heat release to environment.

1.6 Feasibility of The Project

All the necessary information can be obtained within the allocated time, thus this project has potential to be done within the time given. Based on the scope of the project, once the simulation is executed, all the data can be gathered and analysis can be done.

CHAPTER 2: LITERATURE REVIEW

2.1 Industrial Waste Heat

Industrial waste heat can be referred to the unusable form of energy produced from the excess energy required by the industrial process. According to U.S Department of Energy, "… during manufacturing processes, as much as 20-50% of the energy consumed is ultimately lost via waste heat. In some cases, such as industrial furnaces, efficiency improvements resulting from waste heat recovery can improve energy efficiency by 10% to as much as 50%". In this project, process steam condensate at 80^{o}C is used as the source of waste heat. A few industrial processes that contain potential low temperature waste heat are listed as below:

Source	**Temperature, ^{o}C**
Process steam condensate	55-90
Air compressor	27-50
Internal combustion engines	66-120
Liquid still condenser	30-90
Hot process liquid	30-230
Welding machines	30-85

Table 2.1: Source of low temperature waste heat

Recovery of waste heat could increase the efficiency of the process while reduce in utility consumption and cost. However, to recover waste heat a few feasibility factors need to take into account. Those parameters are listed as below;

Parameter	**Description**
Heat quantity	Economically feasible to recover.
Heat quality (temperature)	Higher temperature can lead to greater output quality.
Composition	Corrosive components could lead to the high recovery cost.
Chemical/ physical properties	To determine the amount of heat can be recovered.

Table 2.2: Feasibility factors of waste heat recovery

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2.2 Absorption Heat Pumps (AHP)

Absorption heat pump is a heat pump commonly driven by a heat source such as natural gas, propane, and heated water. As in a standard heat pump, the absorption of heat occurs by the separation and mixing of the binary working mixture (Herold K. E., 1996). This working mixture contains refrigerant as the heat absorber and absorbent to recover the refrigerant in the system. The most commonly used is ammonia (refrigerant) and water (absorbent). This type of heat pump is widely used in commercial heating and cooling and also residential cooling system.

In basic terms, to absorb and release the heat from refrigerant, the relationship between pressure and boiling temperature is exploited. System needs to control this parameter in order to achieve optimum rate of cooling and heating of the refrigerant. Its working principle will be discussed later.

2.3 Absorption Heat Transformer (AHT)

AHT is a system works in the reverse of the AHP. Basically for AHT to work, it may consist of a desorber, a condenser, an evaporator, an absorber and heat exchanger (economizer). Below is the function of equipment used in this system.

Equipment	Function
Separator	To split working mixture
Condenser	To cool down refrigerant
Evaporator	To supply heat to refrigerant
Absorber	To recover heat from refrigerant
	To absorb refrigerant
Heat Exchanger	To preheat working mixture.

Table 2.3: List of equipment used in AHT

In general, the same temperature of waste heat is supply to the desorber and evaporator and absorber will receive the upgraded heat. The AHT cycle uses a refrigerant-absorbent solution rather than pure refrigerant as the working fluid. In this system, the absorbent acts as a secondary fluid to absorb the refrigerant in its vapor phase (Sozen A., Performance Improvement of Absorption Heat Transformer, 2007).

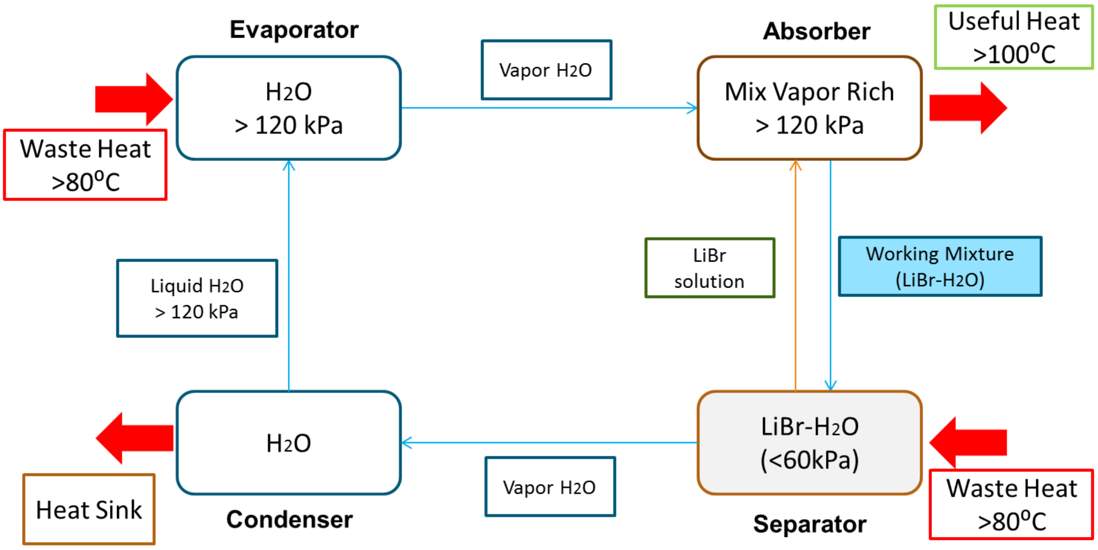


Figure 2.1: Process flow diagram of AHT

Based on Figure 2, the refrigerant-absorbent solution passing through the solution pump to the absorber is referred as a strong solution where it is rich in LiBr. While the solution returning from the absorber to the desorber contains low concentration of LiBr compared to the solution being pumped from the desorber to the absorber and is therefore referred to as weak solution (Yin J. S. L., 2000).

The operating sequence of the AHT shown in Figure 1 is as follows; the working mixture is heated by waste heat in desorber (Romero R J, 1997). This working mixture is heated at low pressure condition so that they can vaporize easily. Then, the refrigerant vapor is pumped to the condenser and the heat will be drawn from the refrigerant vapor. This is to allow the refrigerant change it from back to liquid and ready to absorb more heat in evaporator. The liquid refrigerant is then pumped to the evaporator by high pressure steam. In evaporator the liquid refrigerant received waste heat at higher pressure and temperature (relationship of temperature and pressure) and change to vapor. The refrigerant vapor is absorbed in the refrigerant-absorbent solution that enters the absorber. Thus the heat of absorption is transferred to the cooling water of the absorber and boosts its temperature (Ishida M., Graphical Exergy Study on Single Stage Absorption Heat Transformer, 1999). The weak solution is transferred to the separator, where some refrigerant vapor is removed from it, then returned in a strong state to the absorber. Thus, the AHT has the unique capability of rising the temperature of the solution above the waste heat source temperature. The performance of the AHT is improved by installing a counter flow heat exchanger between the weak and strong solutions. This heat exchanger increases the amount of sensible heat transported by the weak solution from the absorber to the separator.

Commonly, this AHT is operated by lithium bromide- water because of their desirable properties in lifting the output temperature. However, they exhibit a drawback where the crystallization occurs at certain temperature. This limits the output temperature that can be obtained from AHT where the concentration of salt in solution only 65% maximum.

The process flow diagram above is produced from the simulation that has been done using HYSYS. Operated by LiBR-H_2O, this process is to be used as comparison for ADHT system. Later, the result from simulation will be discussed to give better understanding and interpretation.

There are a few differences between absorption heat pump and absorption heat transformer. The advantages of absorption heat transformer are tabulated as below.

Characteristic	AHP	AHT
Heat source	Natural gas/ electricity	Waste Heat
Typical working mixture	Ammonia-Water	Lithium Bromide-Water
System efficiency	Heat produced over consumption of heat source	Literally, heat source is costless.
Purpose	Water heating	Upgrade temperature of waste heat

Table 2.4: Difference between AHP and AHT

2.4 Absorption Demixing Heat Transformer (ADHT)

ADHT is a type of heat pump that operated by partially miscible working mixture. This partially miscible mixture have a different physical properties compare to the binary working mixture used in AHT. Under low pressure and temperature, this mixture exhibits non-miscible of two liquid phases. These liquid phases are in thermodynamic equilibrium but have distinct composition (Noubli H., Development of a New ADHT: Cycle and Working Mixture Optimization, 2010).

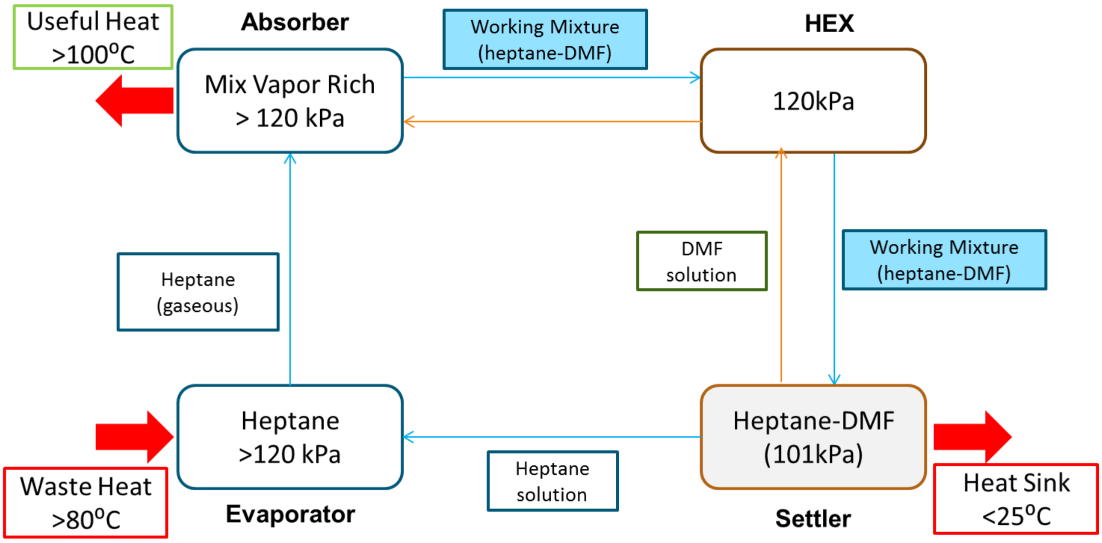


Figure 2.2: Process flow diagram of ADHT

Basic ADHT consists of settler, evaporator and absorber for heat generation while the output heat is recovered by condenser (see Figure 3). Operated by partially miscible working mixture, the mixture is cooled down to the room temperature (23-25°C) in settler by the heat sink. Then, this mixture will start to split into two liquid phases; refrigerant-rich and absorbent-rich liquids. This process happens without any energy input. The refrigerant-rich liquid is then pumped into evaporator by high pressure pump to receive waste heat while absorbent-rich liquid is pumped straight into the top inlet of absorber. In evaporator, refrigerant-rich liquid is converted to the refrigerant-rich vapor to increase its ability to carry more heat to the absorber. Refrigerant-rich vapor is then supplied into bottom inlet of the absorber. In absorber, refrigerant-rich vapor and absorbent-rich liquid is mixed by counter current direction (Ranger P. M., Modeling of a New Absorption Heat Pump Combining Rectification and Reverse Rectification, 1990). The absorption of this vapor will produce high temperature heat. The leaner vapor exiting from top outlet of the absorber is the flow into condenser. In condenser, leaner vapor will be converted into leaner liquid and the heat will be recovered as high quality heat. The leaner liquid will be pumped back to the separator and mixed with the effluent from the bottom outlet of absorber and forms the working mixture back thus the new separation cycle will start.

To understand the objective of ADHT, there are difference between the working principle of AHT and ADHT (see Figure 2). AHT is operated by evaporating of refrigerant in desorber by waste heat and then condensing at a lower temperature (Niang M. C. T., A New Trend in Heat Recovery From Wastes By The Use Of Partially Miscible Working Fluids, 1997). Hence, leads to the higher quantity of waste heat needed and lowering the efficiency of the system.

Absorption Demixing Heat Transformer (ADHT)	**Absorption Heat Transformer (AHT)**
Working mixture selection based on miscibility gap.	Working mixture selection based on volatility gap.
Using settler/ separator for working mixture separation.	Using desorber for working mixture separation.
Working mixture needs to cool down for separation.	Working mixture needs to heat up for separation.
Less exergy destructive	High exergy destructive at condenser [5].

Table 2.5: Difference of ADHT and AHT

2.5 Working Mixture

2.5.1 Criteria of Working Mixture

In order for heat transformer to have high Coefficient of Performance (COP), the suitable working mixture must be chosen. The suitable combination of working mixture need to be evaluated based on the thermodynamic criteria (Yin J. S. L., 2000). The good working mixture should have the ability to completely miscible at certain condition and exhibit the region where it can be separated into two phases (refrigerant-absorbent).The pairs of working mixture must exhibit the general as shown in the Figure 5.

In the cycle of heat absorption, working mixture undergo two important phases; separation and absorption. Separation occurs at the separator/ settler where working mixture is separated into refrigerant and absorbent. This process usually takes place at pressure lower than 1 atm. The absorption phase occurs when in the absorber when the refrigerant is been absorbed by absorbent and forms homogenous working mixture. This process requires operating pressure more than 1 atm to have the completely miscible working mixture.

Generally, to evaluate the performance of the heat absorption cycle, there are three conditions need to be taken into account; the amount of heat enthalpy in term of temperature, the vapor-liquid equilibrium and the working mixture (liquid) separation process. In the cycle, the consistency of physical properties must be observed. The follow conditions must be observed.

1. Separation of liquid phase must occur at separator/ settler.
2. Complete absorption is occurred in absorber.
3. No further separation occurs in evaporator.
4. The enthalpy will increase as temperature increase at fixed concentration.

In general, both refrigerant and absorbent must exhibit high thermal conductivity to increase the heat transfer coefficient, low viscosity to reduce the pressure drop and must be from non-corrosive and non-toxic materials, chemical and physically stable along the process and available in large quantity (economical). Usually for AHT, the common working mixtures are; LiBr-H_2O, ammonia- H_2O and NaOH- H_2O.

However, for ADHT system operated by partially miscible working have slightly different criteria Commonly, this criteria can be found in the mixture of polar such as saturated hydrocarbon and non-polar compounds such as water, ketones, alkanes and alcohols. Under low pressure and temperature, the mixture is composed of two distinct liquid phases. This phenomenon is called demixtion (Niang M. C. T., 1998). Instead of receiving heat at separator for separation, partially miscible mixture needs to be cooled down to the temperature lower than upper critical solution temperature (UCST). UCST is the critical temperature which the components in a mixture are miscible at all degree. UCST is also dependent to the concentration and pressure. At certain concentration and pressure the mixture exist as non-miscible. This mixture will form two distinct liquid phases at the temperature lower than UCST hence the separation can occur at lower thermal energy requirement. The absorption process is conducted at temperature above the UCST to make sure that the mixture is completely miscible. At high pressure, the degree of miscibility is increasing and the mixture will form homogeneous liquid phase. Hence, this condition will bring up the temperature and convert the more volatile component to vapor form.

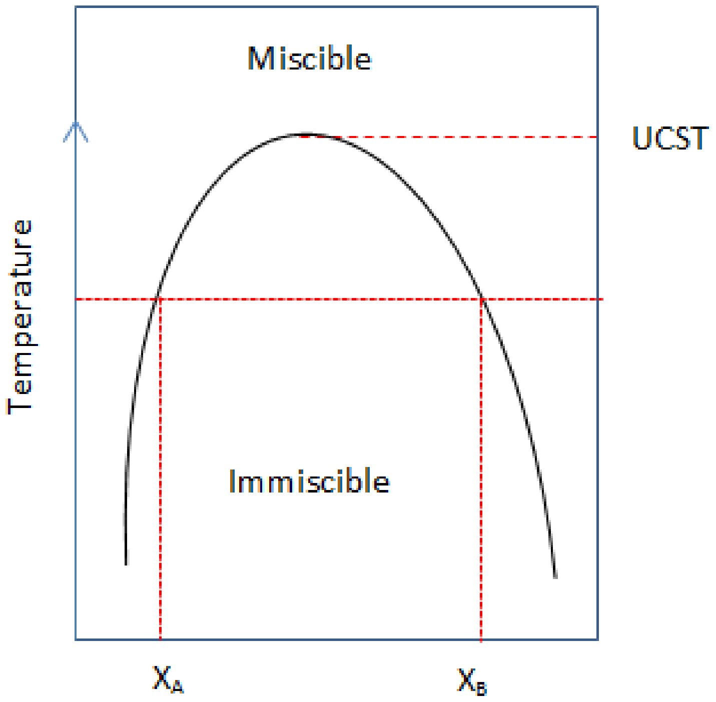


Figure 2.3: General Upper Critical Solution Temperatur diagram

Criteria	Reason
High temperature output	To have higher thermal energy in refrigerant.
High temperature lift	To have reasonable quality of heat compare to waste heat injected to the system.
High efficiency	To produce higher quality of heat.
	To have higher percentage of waste heat converted to high quality heat.

Good thermodynamic properties	High heat of vaporization for to increase the heat absorption by refrigerant.
Good chemical/ physical properties	Low viscosity to reduce the flowrate of working mixture.
	Non-flammable, non-toxic and non-explosive
Economical	Can be operated at optimum pressure hence can reduced the operating cost.

Table 2.6: Criteria for working mixture selection for AHT

Criteria	Reason
Exhibit a wide miscibility gap at low temperature.	To reduce the difficulty for separating working mixture at room temperature.
Density difference between liquid phases.	To have distinct phase difference so that the purity of refrigerant and absorbent at their respective destination is higher.
Interfacial tension.	To increase the immiscibility of the working mixture.

Table 2.7: Criteria for partially miscible working mixture in ADHT

Working mixture of ADHT also need to possess the general criteria required for AHT to be operated as shown below.

Mixture	Required property	Reason
Refrigerant	High latent heat	Refrigerant mass flow reduction
	High critical temperature	Possibility to work at high temperature
	Low liquid heat capacity	Increases the fraction of the heat effectively used for vaporization
Absorbent	Easy absorption of the refrigerant	Fundamental for the process

Absorbent and refrigerant	High thermal conductivity	Increases heat transfer coefficients
	Low viscosity	Increases heat transfer coefficients and decreases pressure drops

Table 2.8: Criteria of refrigerant and absorbent

2.5.2 Lithium Bromide- Water as Working Mixture (AHT)

Criteria	**Refrigerant**	**Absorbent**
	Water	**Lithium Bromide**
Viscosity at 25°C	0.8904 cP	0.4637 cP
Latent Heat	2257 kJ/kg	N/A
Liquid Heat Capacity at 25°C	4.200 kJ/kg.C	N/A
Critical Temperature	374°C	1265°C
Thermal Conductivity	0.6110 W/m.K	0.9269 W/m.K

Table 2.9 Properties of LiBr-H2O

2.5.3 n-Heptane- DMF as Working Mixture (ADHT)

n-Heptane is an alkane group and act as non-polar solvent while DMF is an organic solvent and acts as polar in working mixture for heat transformer. In working mixture, n-heptane acts as absorbent while DMF as refrigerant. It exhibits all the necessary criteria for AHT and also has wide gap of miscibility at low temperature. This mixture has been proposed by Alonso in Performance Simulation of an Absorption Heat Transformer Operating with Partially Miscible Mixtures, 2002. The following table is the criteria in selecting n-heptane-DMF as working mixture.

Criteria	**Refrigerant**	**Absorbent**
	DMF	**n-heptane**
Miscibility	Immisible in heptane	Immiscible in DMF

Viscosity at 25^oC	0.8650 cP	0.3913 cP
Latent Heat	2.447 X 10^4 kJ/kg	4.504 x 10^6 kJ/kg
Liquid Heat Capacity at 25^oC	1.572 kJ/kg.C	1.840 kJ/kg.C
Critical Temperature	347^{o}C	267^{o}C
Thermal Conductivity	0.1645 W/m.K	0.1207 W/m.K

Table 2.10: Selection of n-heptane- DMF as working mixture.

2.6 Evaluation Of Performance

The simulation model is tested by assumed that the system is:-

- All the equipment involved is adiabatic.
- Complete separation of working mixture at separator and settler.
- Both solutions (absorbent and refrigerant) are equilibrium.

2.6.1 Thermal Yield

Thermal Yield is a ratio of the heat recovered by condenser, Q_{ABS} to heat injected at evaporator, Q_{EVA} and separator, Q_{SEP}. For typical AHT the Thermal Yield can be up to 0.48.

$$Thermal\ Yield = \frac{Q_{abs}}{Q_{eva} + Q_{sep}}$$

2.6.2 Temperature Lift

Temperature lift is defines as the difference between the temperature of vapor leaving top outlet of the absorber with the temperature of vapor produced in evaporator. This criterion is to determine the qualitative measurement of heat upgrading process.

$$\Delta T = Tabs - Teva$$

2.6.3 Working Pressure and Temperature

To have good operating condition, ADHT system should be operated at the pressure where the liquid-liquid equilibrium (LLE) and vapor-liquid equilibrium (VLE) are not intersected to each other (Sorensen J. M., 1979). Thus for the starter, this system will be conducted by using 101325 Pa.

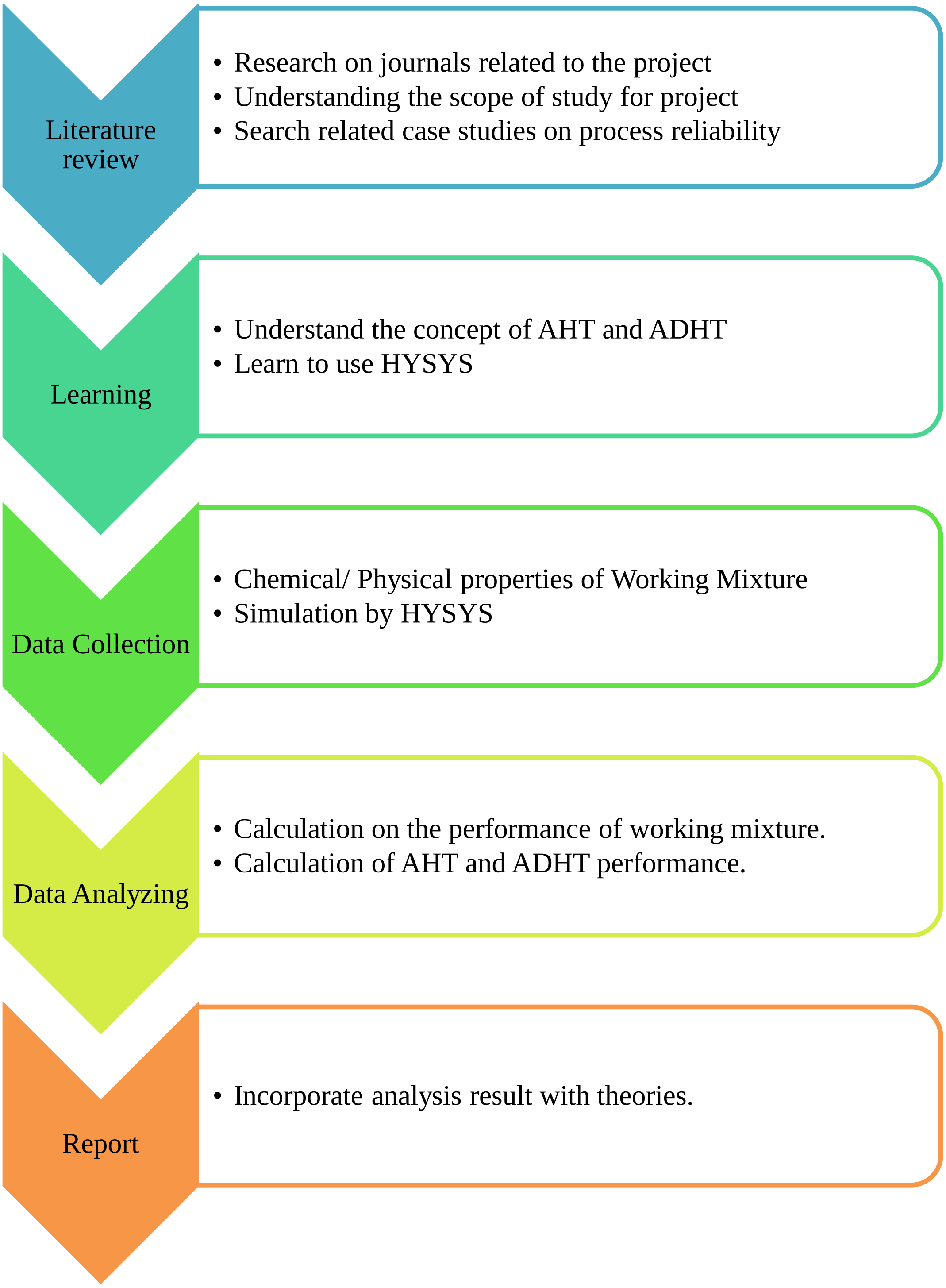
The temperature of settler is the temperature of liquids phase leaving the separator. This temperature can affect the potential of temperature lift by the working mixture. The immiscibility properties of working mixture at low temperature require the separator to be operated at temperature lowers than Upper Critical Solution (UCST) of the refrigerant. UCST is the critical temperature where the miscibility of the mixture also maximum at all proportion. The selection of operating temperature is based on the mole fraction of the refrigerant in working mixture. The higher mole fraction, the lower operating temperature hence the temperature lift will be increased.

2.6.4 Influence of the enthalpy of vaporization

Enthalpy of vaporization is the change of enthalpy to convert one mole liquid mixture to the gas mixture at constant temperature. Thus, the difference enthalpy of vaporization for a component is depending on the chemical nature and its concentration in the solution. When the concentration of refrigerant is high, the enthalpy of vaporization also high and more heat will be absorbed by the vapor and the temperature lift also will be higher.

CHAPTER 3: METHODOLOGY

3.1 Research Methodology



Literature review
- Research on journals related to the project
- Understanding the scope of study for project
- Search related case studies on process reliability

Learning
- Understand the concept of AHT and ADHT
- Learn to use HYSYS

Data Collection
- Chemical/ Physical properties of Working Mixture
- Simulation by HYSYS

Data Analyzing
- Calculation on the performance of working mixture.
- Calculation of AHT and ADHT performance.

Report
- Incorporate analysis result with theories.

Figure 3.1: Project flow chart

3.1.1 Data Collection- Test Parameter

In order to gather all necessary information to evaluate the performance of the system, a few parameter will be tested is listed as below:

i. Mole fraction (concentration) of refrigerant.
    - To find optimum flow rate of absorbent and the amount of heat that absorbed by vapor refrigerant.
    - To optimize the temperature lift.

ii. Operating temperature of separation process.
    - To achieve maximum separation between two liquid phases.

iii. Operating pressure for evaporation process.
    - To make sure the refrigerant vapor can absorb maximum amount of heat without affecting its physical properties.

iv. Absorber molar feed ratio.
    - To find optimum molar flow rate of absorbent, max absorption and higher temperature lift.

3.1.2 Simulation Process Flow

The simulation that has been done for both AHT and ADHT are based on the steps as below:

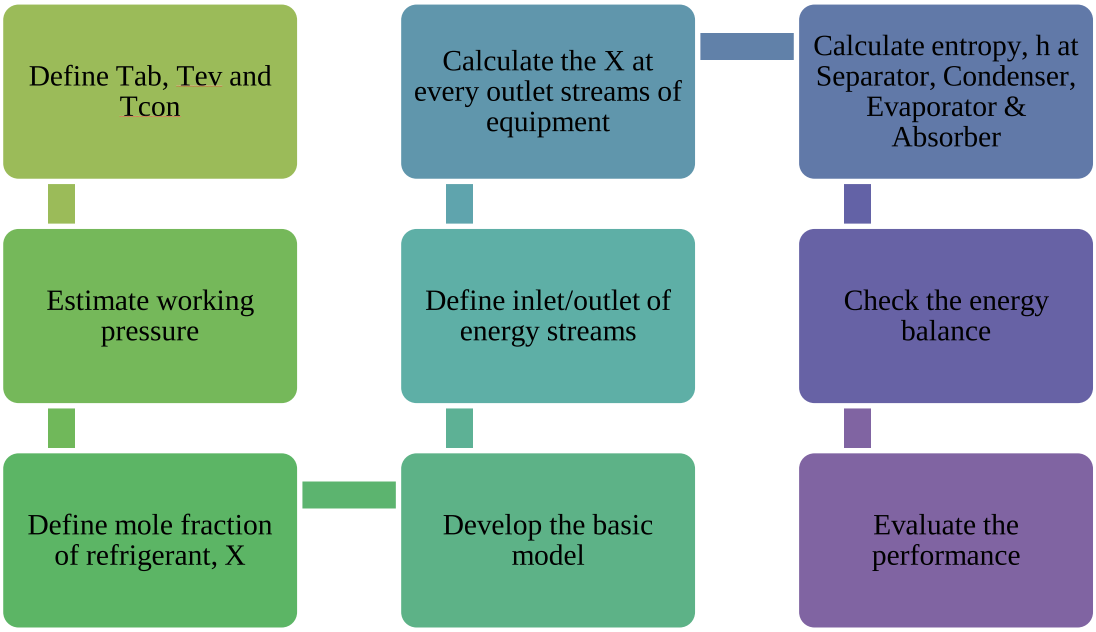
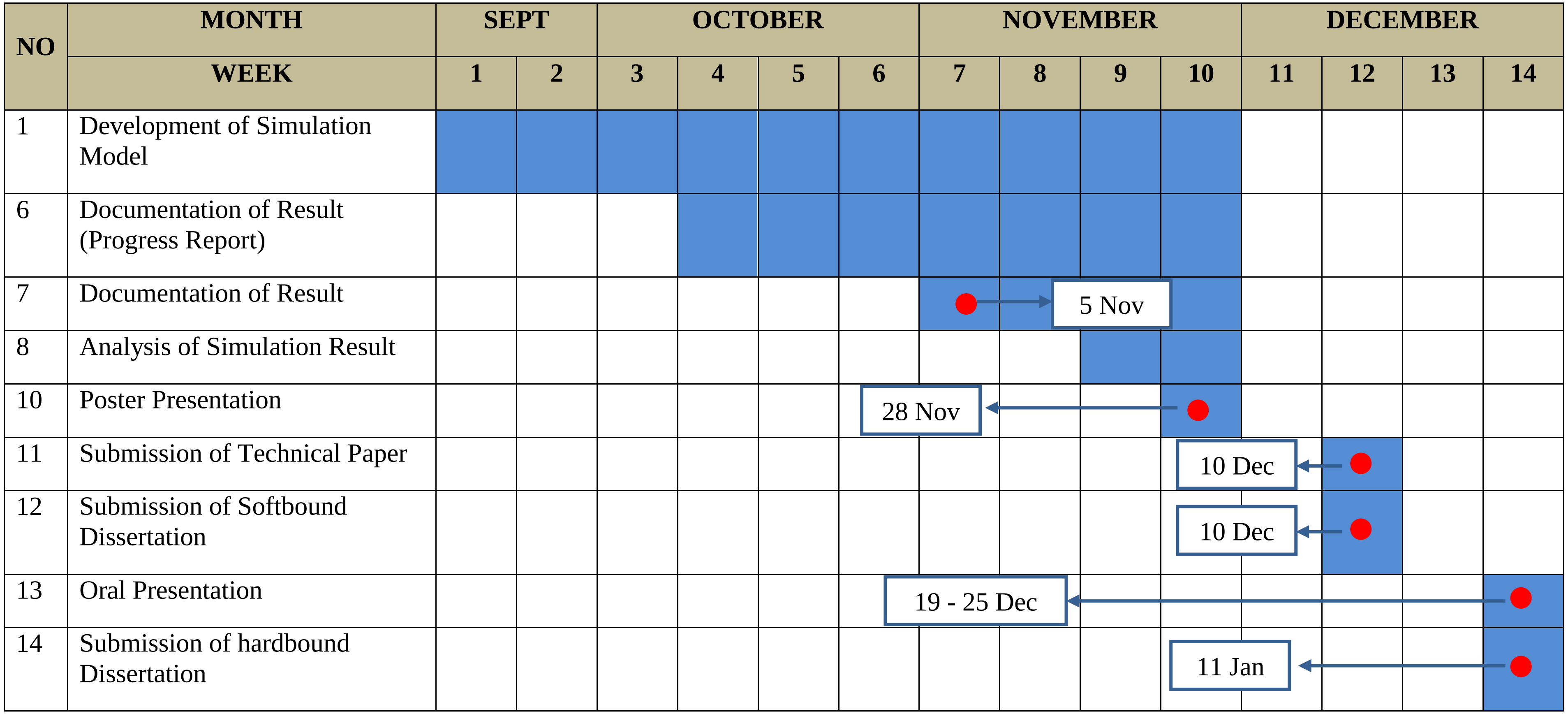


Figure 3.2: Simulation process flow

3.2 Gantt Chart



NO	MONTH	SEPT		OCTOBER				NOVEMBER				DECEMBER			
	WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Development of Simulation Model	■	■	■	■	■	■	■	■	■	■				
6	Documentation of Result (Progress Report)				■	■	■	■	■	■	■				
7	Documentation of Result							■ ●	■	5 Nov	■				
8	Analysis of Simulation Result									■	■				
10	Poster Presentation							28 Nov			■ ●				
11	Submission of Technical Paper											10 Dec	■ ●		
12	Submission of Softbound Dissertation											10 Dec	■ ●		
13	Oral Presentation							19 - 25 Dec							■ ●
14	Submission of hardbound Dissertation											11 Jan			■ ●

Table 3.1: Gantt chart and key milestone of the project

3.3 Software

i. Aspen HYSYS 2006 Integrated Simulation Environment
  - Modeling of heat transformer.
  - Process simulation of the heat transformer.
  - Perform necessary calculation.

ii. Microsoft Excel
  - Data collection and analysis.
  - Perform manual calculation if necessary.

CHAPTER 4: RESULT AND DISCUSSION

4.1 System Operating Parameter

4.1.1 LiBr-H_2O Absorption Heat Transformer

In order to fully utilize the waste heat, there are a few alterations that have been done. The waste heat used in this simulation is fixed at 80$^oC$and a few more assumption for the waste heat is listed as below:

- Type of waste heat: Water (H_2O)
- Supplied temperature: 80^oC
- Pressure: 100 kPa
- Heat capacity: 4.20 kJ/ Kg.^oC

For the AHT system itself, the assumption is listed as below:

- There is no heat losses occur within the system.
- The system is in steady state mode.
- The solution is saturated when leaving the separator.
- The minimum temperature difference, ΔT, between cold stream and hot stream is equal to 10^oC.
- The mechanical energy consumed by the pumps is neglected.

The operating condition is stated as below:

a) **Separator**
  - Pressure- 45.00 kPa
  - Temperature- 81^oC

b) **Condenser**
  - Pressure- 45.00 kPa
  - Temperature- 78^oC

c) **Evaporator**
  - Pressure- 100.00kPa
  - Temperature- 110^oC

d) **Absorber**
  - Pressure- 100.00 kPa
  - Temperature- 30^oC

4.1.2 Heptane-DMF Absorption Demixing Heat Transformer (ADHT)

This system is using the same type of waste heat as AHT, the assumption is stated as below:-

- Type of waste heat: Water (H_2O)
- Supplied temperature: 80°C
- Pressure: 100 kPa
- Heat capacity: 4.20 kJ/ Kg.°C

For the ADHT system itself, the assumption is listed as below:

- There is no heat losses occur within the system.
- The system is in steady state mode.
- The solution is saturated when leaving the separator.
- The minimum temperature difference, ΔT, between cold stream and hot stream is equal to 10°C.
- The mechanical energy consumed by the pumps is neglected.

The operating condition is stated as below:

e) **Settler**
   - Pressure- 100.00 kPa
   - Temperature- 27°C

f) **Solution Heat Exchanger**
   - Pressure- 140.00 kPa
   - Temperature- 110°C

g) **Evaporator**
   - Pressure- 140.00kPa
   - Temperature- 111°C

h) **Absorber**
   - Pressure- 140.00 kPa
   - Temperature- 109°C

Both simulations are tested with the same molar flowrate of working mixture in order to give comparable result.

4.2 Simulation Result

4.2.1 Validation of Simulation Model

There are two simulation model that have been developed; AHT operated by LiBR-H_2O and ADHT operated by heptane-DMF. The preciseness of simulation model of AHT is verified by compared the simulation result with the available data by [6] and the result is shown in Figure 4.

	Published data	**Simulation Model**	**Error Percentage (%)**
T_{eva} (^oC)	**Q_{abs} (kW)**	**Q_{abs} (kW)**	
76	0.477	0.476	0.21
78	0.48	0.478	0.42
80	0.482	0.479	0.62
82	0.484	0.481	0.62
84	0.485	0.483	0.41

Table 4.1: Comparison of effect of evaporator temperature on COP AHT (LiBr-H_2O)

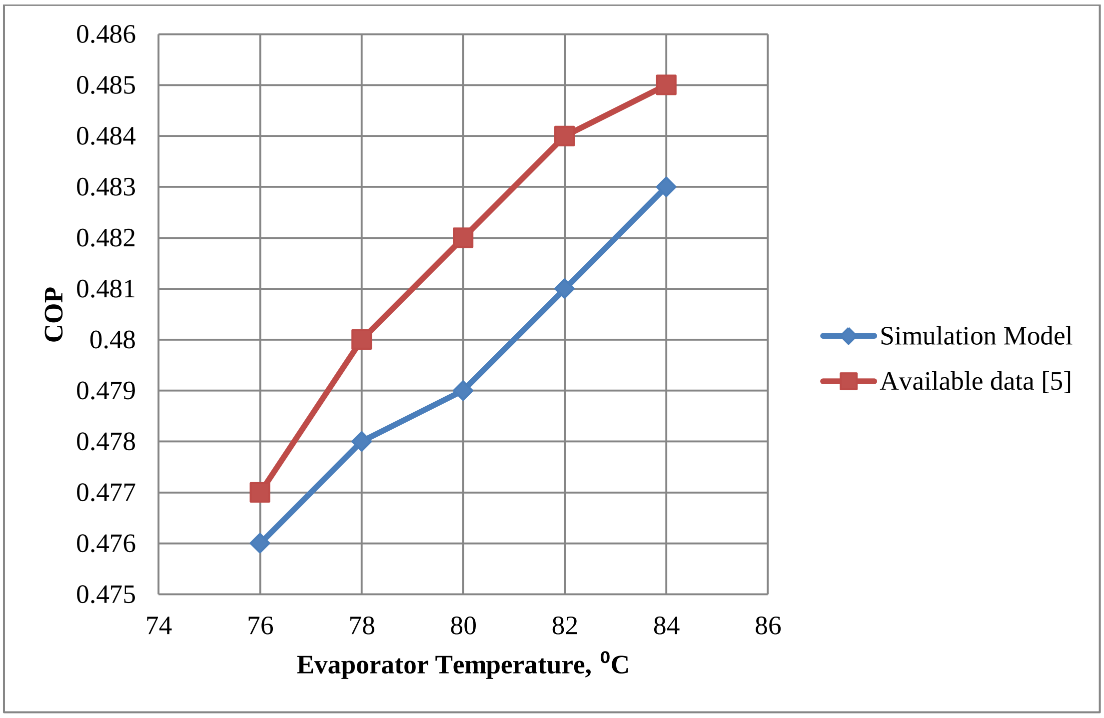


Figure 4.1: Comparison of effect of evaporator temperature on COP AHT (LiBr-H_2O)

The validation of simulation model is based on comparison of COP against the evaporator temperature. As validation purpose, the separator temperature is kept at 90°C, the condenser is at 20°C and absorber is at 120°C. Both data show that the COP is increasing when the evaporator temperature is increased. The overall error percentage is 0.458%. This is because of the amount of heat required to increase the temperature of refrigerant is increasing and heat contained at the absorber also increase.

4.2.2 Temperature Lift, ΔT

External temperature lift, ΔT_e is to evaluate the heat carrier which is the difference between condenser outlet temperature and evaporator inlet temperature.

$$\Delta T_e = T_{\text{condenser outlet}} - T_{\text{evaporator inlet}}$$

While internal temperature lifts, ΔT_i is to evaluate the working mixture itself which is the difference between absorber inlet temperature and evaporator outlet temperature.

$$\Delta T_i = T_{\text{absorber inlet}} - T_{\text{evaporator outlet}}$$

System	Internal Temperature Lift, ΔT_i	External Temperature Lift, ΔT_e
LiBr- H_2O	54.8°C	60.0°C
Heptane- DMF	60.7°C	66.8°C

Table 4.2: Temperature lift of the system

4.2.3 Thermal yield, η_{th}

Thermal yield is the ratio of heat flow recovered from absorber to the waste heat supplied at the evaporator and separator. This is used to evaluate the Coefficient of Performance (COP) of the system.

$$\eta_{th} = \frac{Q_{abs}}{Q_{eva} + Q_{gen}}$$

System	Coefficient of Performance (COP)
LiBr- H_2O	0.48
Heptane- DMF	0.41

Table 4.3: COP of the system

The thermal yields of the system is affected by the supplied temperature to the evaporator, the following result of COPs are obtained from different evaporator temperatures. The amount of heat can be recovered from the absorber is determined by total amount of heat supply to the evaporator. Since the evaporator is operated at higher pressure that separator, the amount of heat needed are higher. Hence, the higher supply temperature to the evaporator, the higher heat contain of the working mixture in absorber. Thus, the amount of heat can be recovered from the system will be higher. The result is shown as Figure 5 .Under the same operating condition, LiBr-H_2O has better COP then heptane-DMF because of the amount of heat that can be absorbed by the LiBr-H_2O is higher.

4.3 Performance Evaluation and Analysis

Both temperature lift and thermal yield of the system is affected by the following criteria:-

4.3.1 Operating Temperature Of Separator And Evaporator

Temperature can be translated to amount of heat contain in the streams. Both systems have been tested with various temperatures to observe its effects on the heat recovered by the absorber. The result shows below is system operated at 100 kPa and temperature of separator and evaporator are same. The operating temperature for both separator and evaporator are directly supplied by the waste heat.

	Heptane- DMF	**LiBr- H_2O**
T_{eva} (^oC)	**Q_{abs} (kW)**	**Q_{abs} (kW)**
120	34.13	64.96
122	44.23	73.97
124	53.71	84.63
126	62.95	95.83
128	72.28	105.21

Table 4.4: Effect of evaporator temperature on heat recovered from absorber

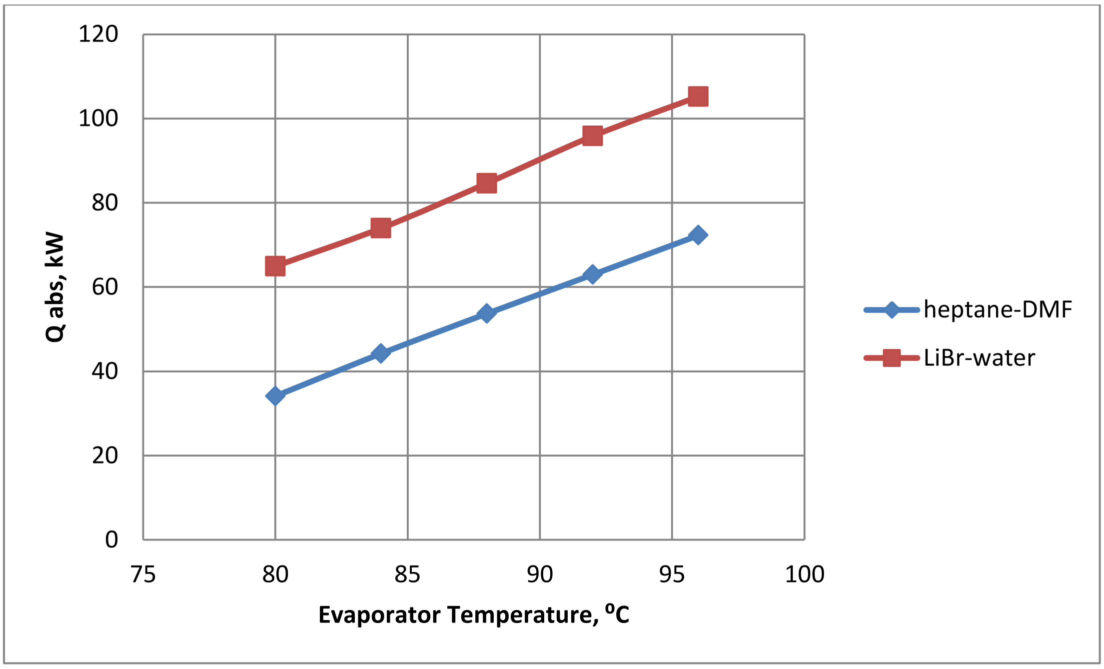


Figure 4.2: Effect of evaporator temperature on heat recovered from absorber

From the result above we can conclude that as the temperature of separator and evaporator increase, the heat of absorption also increases. Hence the temperature lift will be higher and the value of heat recovered also increase.

The thermal yields of the system also affected by the supplied temperature, the following data are resulted from various supplied temperature. The amount of heat can be recovered by the process is determined by total amount of heat needed for the process. The higher supplied temperature leads to the higher heat contain in the working mixture. Hence, the amount of heat can be recovered from the system will be higher. The result is tabulated as below:

	COP		**Error**
T_{eva} (^oC)	**Heptane- DMF**	**LiBr- H_2O**	**Percentage (%)**
76	0.454	0.476	4.62
78	0.457	0.478	4.40
80	0.461	0.479	3.76
82	0.464	0.481	3.53
84	0.467	0.483	3.31

Table 4.5: Effect of evaporator temperature on COP of the heptane-DMF and LiBr-H_2O system

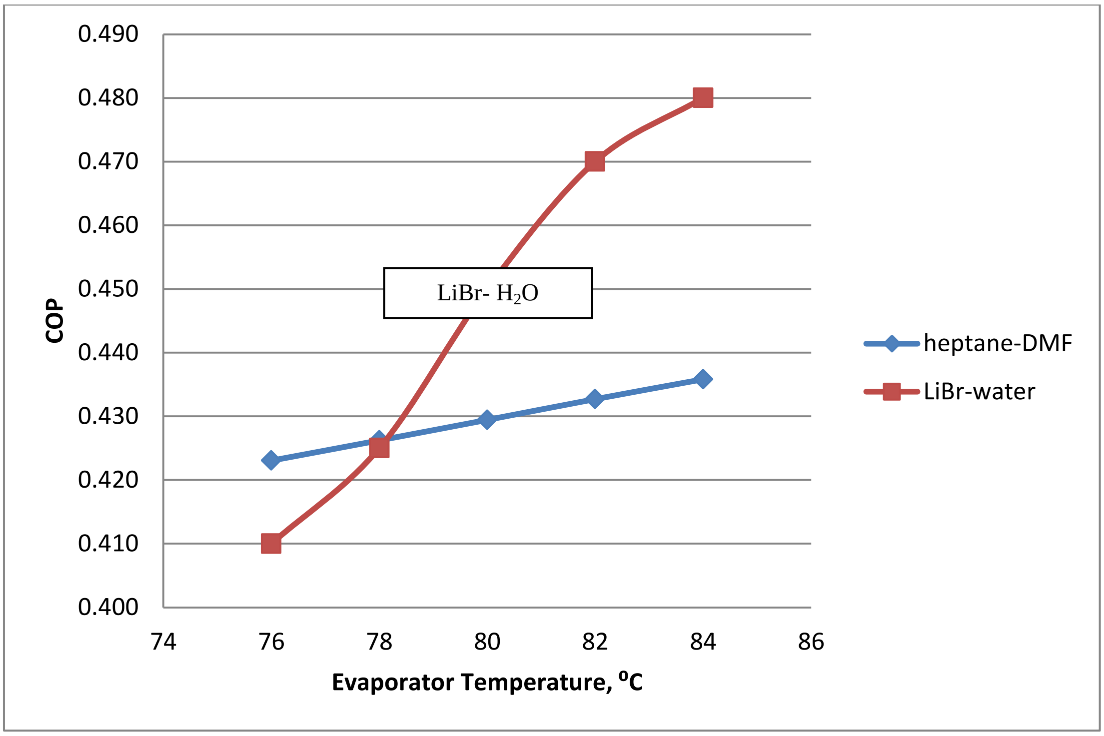


Figure 4.3: Effect of evaporator temperature on COP of the heptane-DMF and LiBr-H_2O system

Under the same operating condition, LiBr-H_2O has better COP then heptane-DMF because of the amount of heat that can be absorbed by the mixture itself. The heat that needs to be supplied by evaporator also depends on the temperature of condenser (LiBr-H_2O) and settler (heptane-DMF).

The result shows that the higher temperatures of condenser or settler, the lower heat need to be supplied by evaporator. This is due to the less destruction exergy in the solution. The result is tabulated as below.

	Q_{eva} (kW)	
T_{con} (°C)	**Heptane- DMF**	**LiBr- H_2O**
20	88.56	93.64
25	86.78	92.88
30	84.98	92.12
35	83.15	91.36
40	81.31	90.6

Table 4.6 Effect of condenser / settler temperature on heat required by evaporator

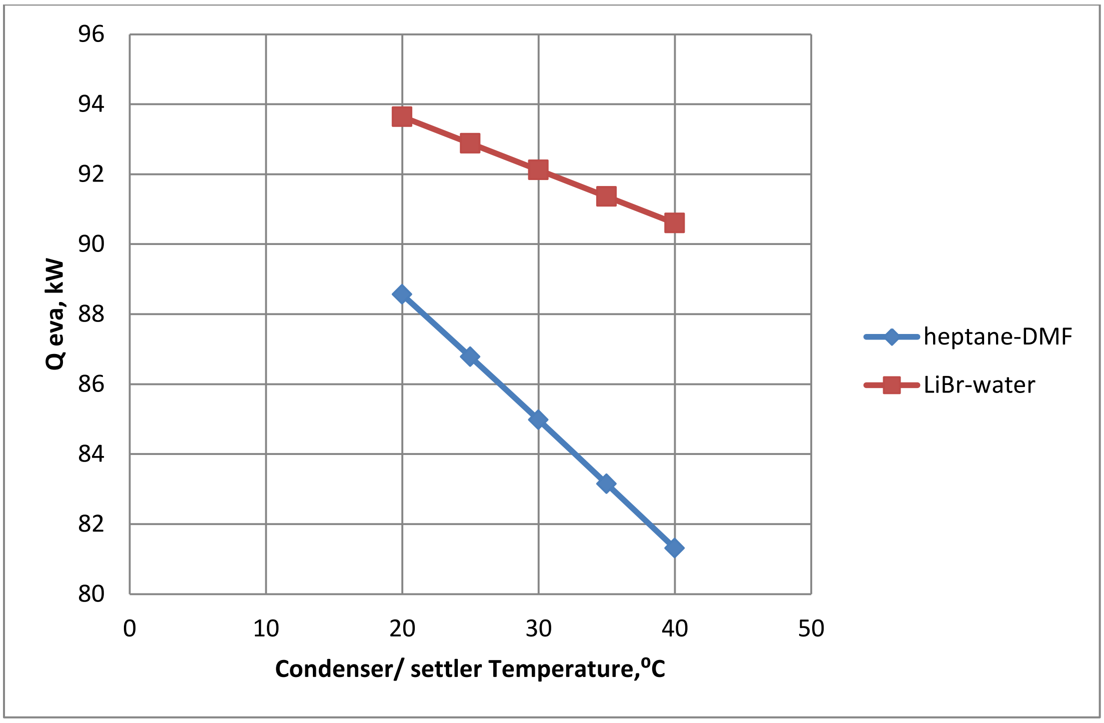


Figure 4.4: Effect of condenser / settler temperature on heat required by evaporator

4.3.2 Operating Pressure Of Separator And Evaporator

Absorption heat transformer (AHT) is operating under different pressure for separation (separator) of working mixture and evaporation of refrigerant. The high pressure region is evaporator and absorber while low pressure region is separator and condenser. While absorption demixing heat transformer (ADHT) can be operated under one operating pressure, 101 kPa. This is because at atmospheric pressure, heptane- DMF can be separated easily.

	Heat (kW)	
P_{eva} (kPa)	**Heptane- DMF**	**LiBr- H_2O**
80	75.2	92.03
90	76.42	92.23
100	77.53	92.41
110	78.57	92.57
120	79.54	93.1

Table 4.7 Effect of evaporator pressure on heat required by evaporator

Evaporation process is necessary to provide water or DMF with thermal energy from waste heat. Thus, to have higher amount of heat, this process must be carried out under higher pressure than the pressure for separation process. The graph below shows the effect of evaporator pressure towards the heat supplied by waste heat to the evaporator. As the pressure increase, the temperatures also increase.

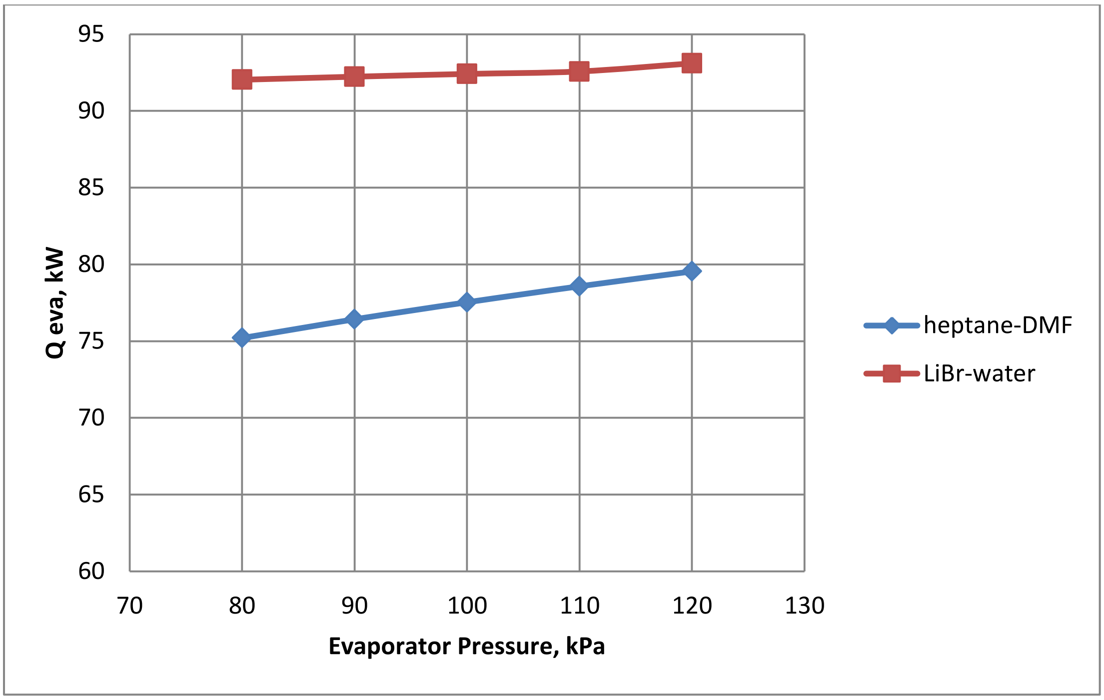


Figure 4.5: Effect of evaporator pressure on heat required by evaporator

4.3.3 Mole fraction of refrigerant (H_2O, DMF)

The concentration of working mixtures is related to the mole fraction of refrigerant. An ideal working mixture should exhibit low viscosity but high enough thermal conductivity. To investigate the effect of refrigerant concentration towards the heat needed by evaporator, the mole fraction of refrigerant is varied from 0.40-0.60. The result is tabulated as below:

	Q_{eva} (kW)	
Mole Fraction, X	**Heptane- DMF**	**LiBr- H_2O**
0.40	63.2	62.79
0.45	70.65	70.68
0.50	76.800	78.56
0.55	82.77	86.45
0.60	88.56	94.33

Table 4.8: Effect of refrigerant mole fraction on heat required by evaporator

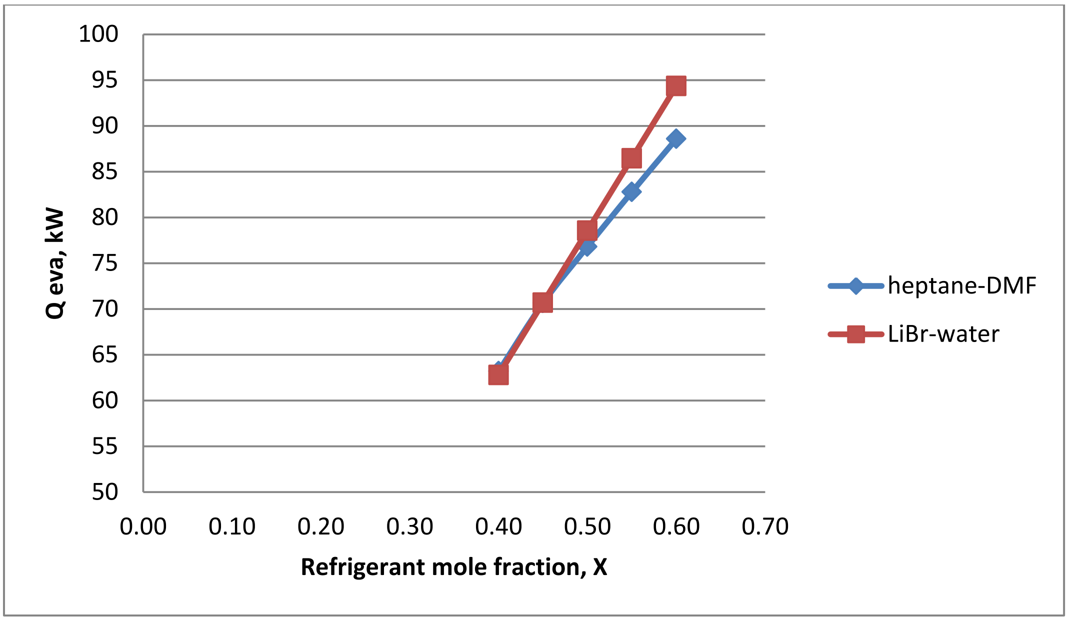


Figure 4.6: Effect of refrigerant mole fraction on heat required by evaporator

The simulation result shows that the increasing of mole fraction of water and DMF, the heat supplied to evaporator also increase. Hence, the amount of recovered heat also increases. The graph above shows that LiBr-H_2O has significant increment compare to the heptane-DMF. This is because of the increasing of water flowrate, hence heat supplied also increase in order to satisfy the water heat capacity. However, due to the crystallization problem, the system operated by LiBr–H_2O is feasible to be operated with the temperature under 200^oC.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The project aims to present the new working mixture for industrial application to obtain useful heat. The simulation has been executed using waste heat at 80^oC and to produce water vapor at 150^oC. The result and analysis prove that both systems are equally favorable in utilizing the waste heat. AHT and ADHT exhibit the potential to boost the temperature of medium or low level waste heat. The simulation of LiBr-H_2O system and heptane-DMF system has proven that:

- When the temperature of condenser increase, the heat supply needed by evaporator will decrease.
- Increasing in temperature of evaporator and separator will result in increasing of COP.
- Increasing in temperature of evaporator and separator will result in increase of heat recovered by absorber.
- The higher operating pressure of evaporator will increase the heat needed by evaporator.
- Both systems have comparable COP.

As conclusion, both systems are utilizing about 50% of the waste heat supplied to the system hence we can conclude that from the result obtained ADHT operated by heptane-DMF as working mixture has potential to be applied in industries. All the objectives of this project are achieved and proven from the result obtained.

5.2 Recommendation

The result obtained from simulation is based on the assumption and at the steady state condition. Thus, development of pilot unit for experimentation purpose is recommended in order to obtain more reliable data. ADHT system is operated by partially miscible working mixture thus a mixture such as cyclohexane- dimethyl sulfoxide (DMSO) and water- furfural is worth to be used in next simulation (Niang M. C. T., 1998). The mechanical and electrical energy should be taken into account so that the real COP can be obtained.

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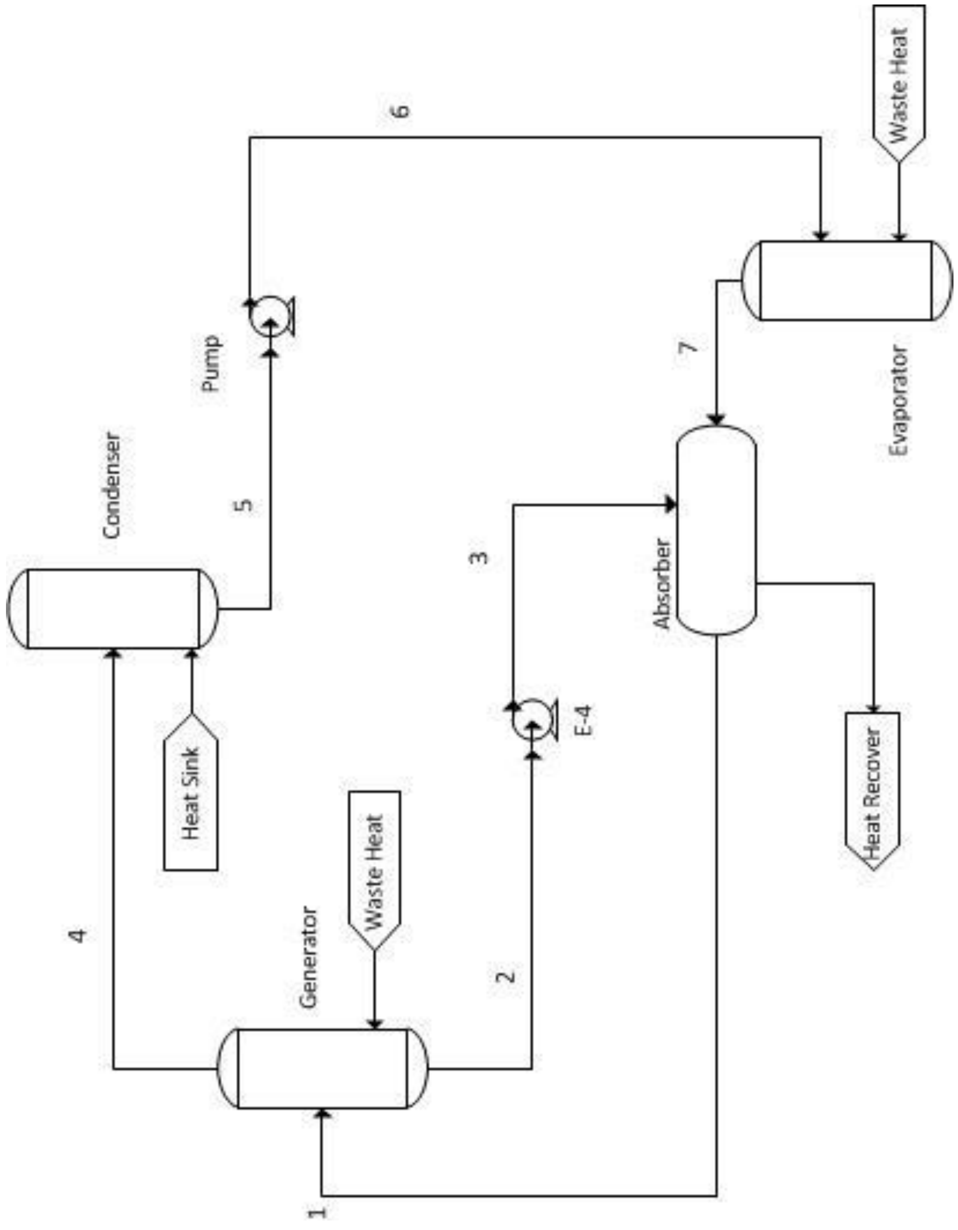
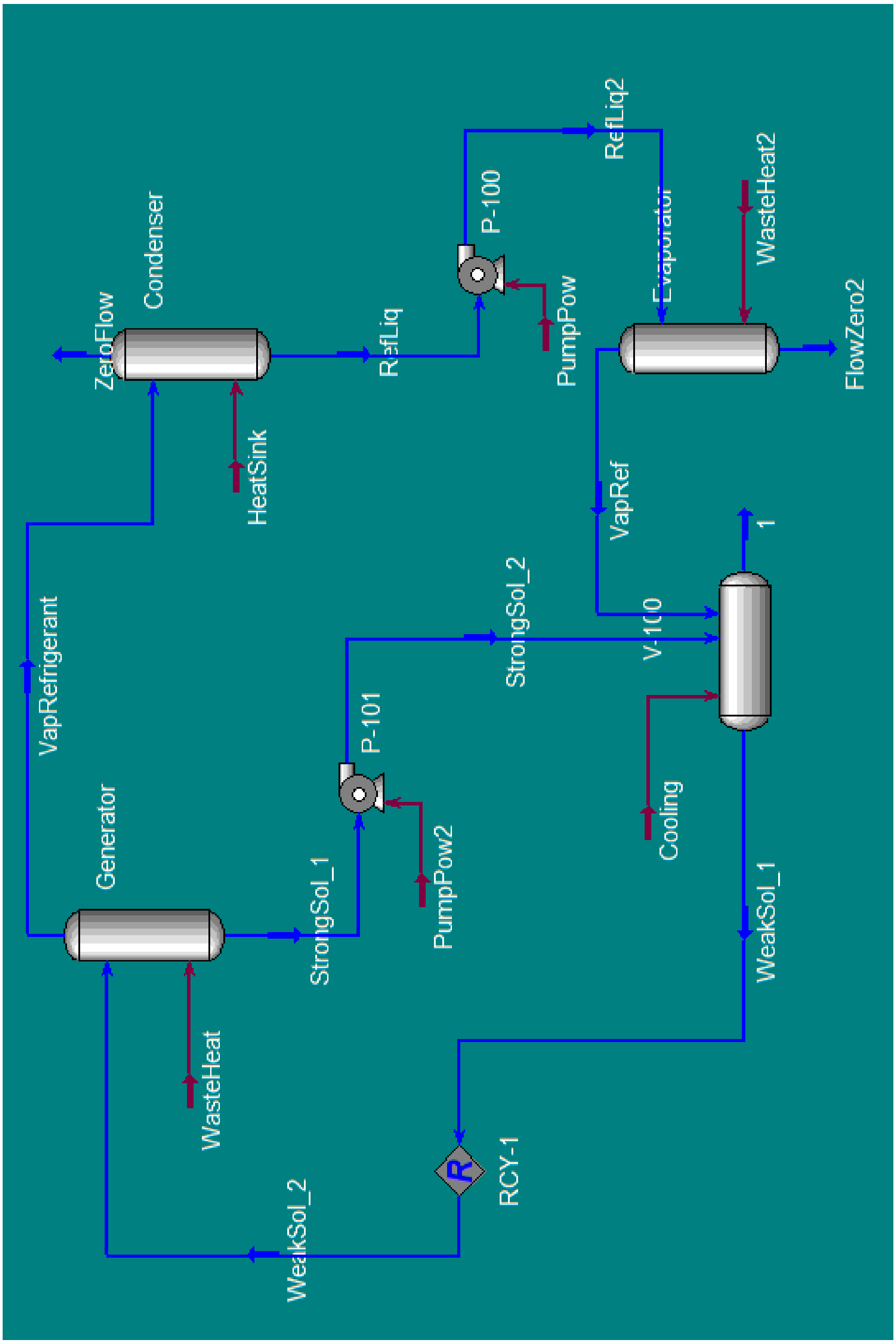
APPENDIX

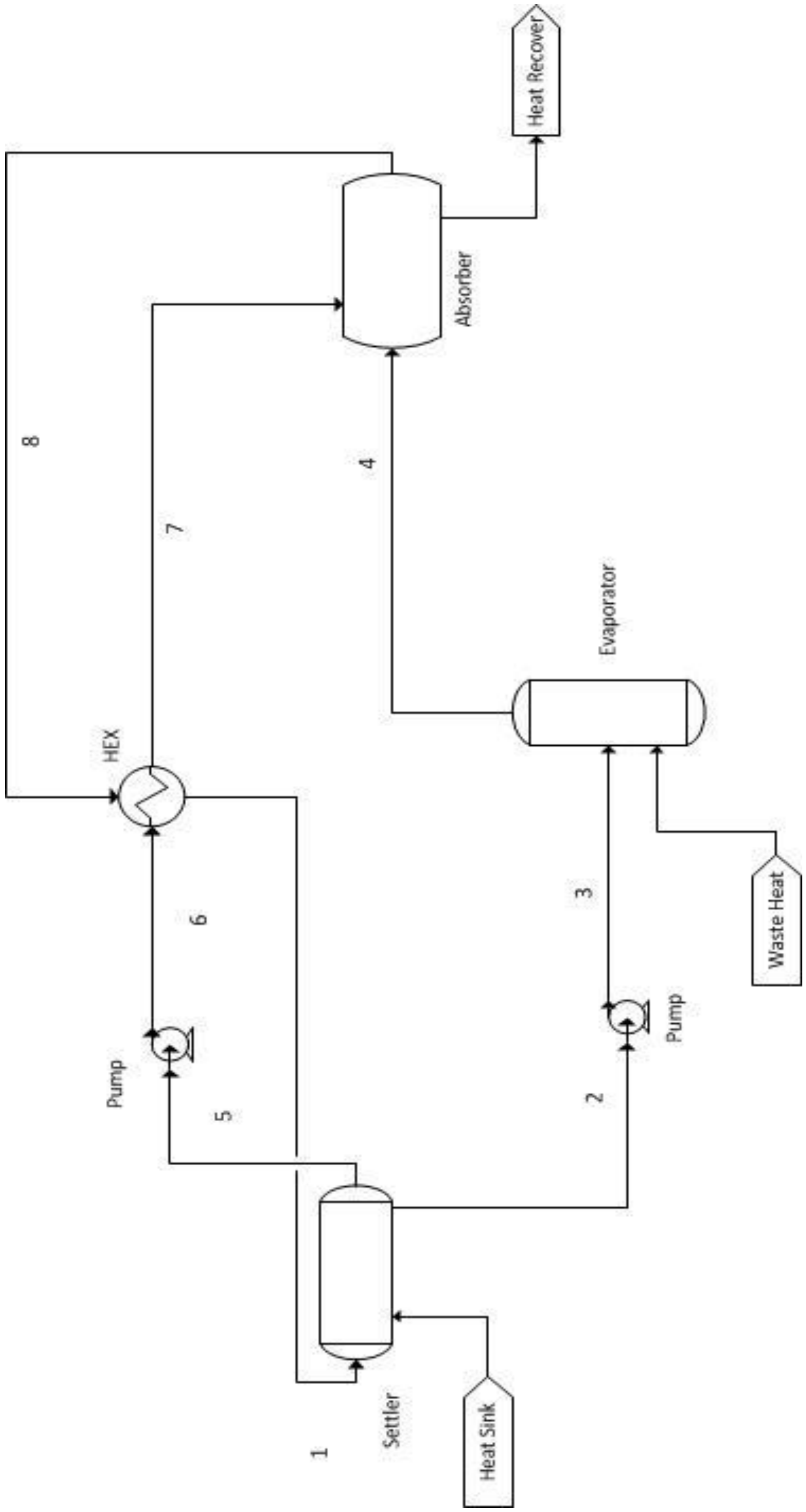
Absorption Heat Transformer: LiBr-H_2O



HYSYS simulation: LiBr-H_2O



Absorption Heat Transformer: Heptane-DMF



HYSYS simulation: Heptane-DMF